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On the dynamics of the AB Doradus system

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Abstract. We present an astrometric analysis of the binary systems AB Dor A / AB Dor C and AB Dor Ba / AB Dor Bb. These two systems of well-known late-type stars are gravitationally associated and they constitute the quadruple AB Doradus system. From the astrometric data available at different wavelengths, we report: (i) a determination of the orbit of AB Dor C, the very low mass companion to AB Dor A, which confirms the mass estimate of $0.090 M_\odot$ reported in previous works; (ii) a measurement of the parallax of AB Dor Ba, which unambiguously confirms the long-suspected physical association between this star and AB Dor A; and (iii) evidence of orbital motion of AB Dor Ba around AB Dor A, which places an upper bound of $0.4 M_\odot$ on the mass of the pair AB Dor Ba / AB Dor Bb (50% probability). Further astrometric monitoring of the system at all possible wavelengths would determine with extraordinary precision the dynamical mass of its four components.

Key words. astrometry – stars: kinematics – stars: binary – stars: low mass stars: individual (AB Doradus) – stars: individual (Rst 137 B) –

1. Introduction

Astrometry, one of the most classical astronomical disciplines, provides unambiguous mass estimates of celestial bodies via observations of the orbits of binary or multiple systems, as projected on the sky (see, e.g., Kovalevsky 1995). The precise determination of stellar masses is fundamental in astronomy, as this parameter is the primary input to test stellar evolutionary models that provide widely used mass-luminosity relations. In particular, the calibration of the mass-luminosity relation for the lower end of the main sequence is of special interest, since it permits the derivation of the physical properties of very-low-mass (VLM) stars and substellar objects. However, a model-independent measurement of the mass of these objects is a most demanding task that requires the astrometric follow-up of VLM stars in binary systems (e.g. Lane et al. 2001; Bouy et al. 2004; Golimowski et al. 2004; Close et al. 2005). One of the few VLM objects with astrometric detections is AB Dor C, the companion to AB Dor A.

AB Dor A (=HD 36705) is an active K1 star only 14.9 pc away from the Sun. Due to its ultrafast rotation (0.514 days; Innis et al. 1985), AB Dor A is a strong emitter at all wavelengths, and it has been extensively observed from radio to X-rays (Lim et al. 1992; Mewe et al. 1996; Vilhu et al. 1998; Güdel et al. 2001). AB Dor A possesses a low-mass companion, AB Dor C, which induces a reflex motion first detected by very-long-baseline-interferometry (VLBI) and the Hipparcos satellite (Guirado et al. 1997). Recently, Close et al. (2005) [CLG] obtained a near-infrared image of AB Dor C, providing the first dynamical calibration of the mass-luminosity relation for low mass, young objects. AB Dor A has another physical companion, AB Dor B (=Rossiter 137 B, =Rst 137 B), a dM4e star, which is also a rapid rotator with a 0.38 day period and is separated from AB Dor A by 9" (Lim 1993). Based on their young age (CLG), common proper motions, and common radial velocities (Innis, Thompson & Coates 1986), it is believed that both stars may be associated. In turn, CLG found AB Dor B to be a tight binary (AB Dor B=AB Dor Ba and AB Dor Bb).

AB Dor C is the first calibration point for evolutionary tracks in the young VLM regime. From comparison with theoretical predictions, CLG found that the dynamical mass of AB Dor C is almost twice than predicted by evolu-

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tionary models (Chabrier et al. 2000), which suggests that models tend to underpredict the mass of young VLM objects. In this context, a precise estimate of the dynamical mass of AB Dor C is extremely important. In this paper we report the details of an improved method to determine the mass of AB Dor C, which confirms the value of $0.090\,\mathrm{M}_\odot$ given by CLG. We also report on the sky motion of AB Dor Ba, which shows a nearly-identical parallax to that of AB Dor A and evidence of the long-term orbital motion around AB Dor A.

2. Astrometric Data

In Table 1 we summarize the available astrometric data of the AB Doradus system, which include absolute positions of AB Dor A and AB Dor Ba, relative positions of the 9" pair AB Dor A / AB Dor Bb, and relative positions of the closer pairs AB Dor A / AB Dor C and AB Dor Ba / AB Dor Bb. New absolute positions of AB Dor Ba are presented in this table; they have been obtained from the same VLBI observations that were used to make the astrometric analysis of AB Dor A reported by Guirado et al. (1997). Given the 9" separation, AB Dor A and AB Dor Ba lie within the primary beam of each of the telescopes and thus can be observed simultaneously for efficient cancellation of atmospheric systematic errors. The interferometric array has much finer resolution (a few milliarcseconds) and, therefore, the interferometric data for AB Dor Ba could be extracted and processed following the same procedures as described in Sect. 2 of Guirado et al. (1997) for AB Dor A. This in-beam technique is widely used in VLBI observations (e.g. Marcaide & Shapiro 1983; Fomalont et al. 1999). On the other hand, the relatively low brightness of AB Dor Ba (V=12.6; Collier Cameron & Foing 1997) explains the absence of Hipparcos data for this star. In Sect. 3, we revisit the astrometry of the different pairs shown in Table 1.

3. Astrometric Analysis

3.1. AB Dor A / AB Dor C : Orbit Determination

The infrared image of AB Dor C provided the astrometric data that was used by CLG to constrain the elements of the reflex orbit. The weakness of this procedure was that the relative position AB Dor A/AB Dor C was not included in the fit, rather it was only used as a discriminator of the orbits that plausibly fit the VLBI/Hipparcos data. In this section, we re-estimate the mass of AB Dor C using a much improved method that estimates the reflex orbit of AB Dor A by simultaneously combining both the existing VLBI/Hipparcos AB Dor A astrometric data and the near-infrared relative position of AB Dor C. Following the classical approach, we modeled the (absolute) position of AB Dor A (α, δ) at epoch t from the expressions:

$$
\begin{aligned}
\alpha(t) &= \alpha(t_0) + \mu_\alpha(t-t_0) + \pi\, P_\alpha \\
&\quad + S_\alpha(t, X_1, X_2, X_3, X_4, P, e, T_0) \\
\delta(t) &= \delta(t_0) + \mu_\delta(t-t_0) + \pi\, P_\delta \\
&\quad + S_\delta(t, X_1, X_2, X_3, X_4, P, e, T_0)
\end{aligned}
\tag{1}
$$

where t_0 is the reference epoch, μ_α, μ_δ are the proper motions in each coordinate, π is the parallax, P_α and P_δ are the parallax factors (e.g. Green 1985), and S_α and S_δ are the reflex orbital motions in α and δ, respectively. The astrometric parameters ($\alpha(t_0)$, $\delta(t_0)$, μ_α, μ_δ, and π) are linear in Eq. (1). The reflex motion, S_α and S_δ, depends on the seven orbital parameters, namely, a, i, ω, Ω, P, e, and T_0. We have used the Thieles-Innes coefficients (Green 1985), represented by X_1, X_2, X_3, X_4, which are defined as combinations of a, i, ω, Ω. These coefficients behave linearly in Eq. (1), leaving only three non-linear parameters (P, e, and T_0) to solve for in our weighted-least-squares approach.

Since our fitting procedure estimates the orbital parameters of the reflex motion of AB Dor A, the relative separation AB Dor A/AB Dor C provided by the infrared data ($\Delta\alpha'$, $\Delta\delta'$) at epoch t' is included in the fit via the corresponding orbital position of the primary star according to the definition of the center of mass of the system:

$$
\begin{aligned}
\Delta\alpha' &= -(1+q^{-1}) S_\alpha(t') \\
\Delta\delta' &= -(1+q^{-1}) S_\delta(t')
\end{aligned}
\tag{2}
$$

where q is the mass ratio m_c/m_a, with m_a being the mass of the primary and m_c the mass of the companion. The combination of data types in the same fit is reflected in the definition of the χ^2 to be minimized:

$$
\begin{aligned}
\chi^2 &= \sum_{i=1}^{N} \frac{(\alpha(t_i) - \widehat{\alpha}(t_i))^2}{\sigma_\alpha^2(t_i)} + \sum_{i=1}^{N} \frac{(\delta(t_i) - \widehat{\delta}(t_i))^2}{\sigma_\delta^2(t_i)} \\
&\quad + (1+q^{-1})^2 \left[\frac{(S_\alpha(t') - \widehat{S}_\alpha(t'))^2}{\sigma_{S_\alpha}^2(t')} + \frac{(S_\delta(t) - \widehat{S}_\delta(t'))^2}{\sigma_{S_\delta}^2(t')} \right]
\end{aligned}
\tag{3}
$$

where the σ's are the corresponding standard deviations (Table 1) and the circumflexed quantities are the theoretical values of our *a priori* model. The virtue of the definition of χ^2 in Eq. (3) is that the linearity of the orbital parameters is conserved as long as the mass ratio q is not adjusted in the fit. In consequence, m_a is a fixed parameter in our fit (we adopted the value of $0.865\pm0.034\,\mathrm{M}_\odot$, as given by CLG). The mass of the secondary (m_c) will be estimated via an iterative procedure that we outline below:

1. We set *a priori* values of the three non-linear parameters (P, e, and T_0). In particular, we sample the following parameter space: $0 < P < 30$ years, $1990.0 < T_0 < 1990.0 + P$, and $0 < e < 1$. To start this procedure, we need an initial value of m_c. We take a value of $0.095\,\mathrm{M}_\odot$, which corresponds to the central value of the m_c interval given in Guirado et al. (1997).

Table 1. Compilation of all available astrometric data for the AB Doradus system

		AB Dor A		
Epoch	Instrument	α(J2000)	δ(J2000)	Reference
1990.3888	Hipparcos	$5^h\,28^m\,44^s.77474 \pm 0^s.00026$	$-65^\circ\,26'\,56''.2416 \pm 0''.0007$	(1)
1990.5640	Hipparcos	$5^h\,28^m\,44^s.78652 \pm 0^s.00025$	$-65^\circ\,26'\,56''.2272 \pm 0''.0007$	(1)
1991.0490	Hipparcos	$5^h\,28^m\,44^s.77578 \pm 0^s.00024$	$-65^\circ\,26'\,56''.2615 \pm 0''.0007$	(1)
1991.5330	Hipparcos	$5^h\,28^m\,44^s.78942 \pm 0^s.00025$	$-65^\circ\,26'\,56''.0757 \pm 0''.0008$	(1)
1992.0180	Hipparcos	$5^h\,28^m\,44^s.78202 \pm 0^s.00024$	$-65^\circ\,26'\,56''.1160 \pm 0''.0009$	(1)
1992.2329	VLBI	$5^h\,28^m\,44^s.77687 \pm 0^s.00019$	$-65^\circ\,26'\,56''.0049 \pm 0''.0007$	(1)
1992.6849	VLBI	$5^h\,28^m\,44^s.80124 \pm 0^s.00018$	$-65^\circ\,26'\,55''.9395 \pm 0''.0006$	(1)
1993.1233	VLBI	$5^h\,28^m\,44^s.78492 \pm 0^s.00024$	$-65^\circ\,26'\,55''.9137 \pm 0''.0008$	(1)
1994.8137	VLBI	$5^h\,28^m\,44^s.81768 \pm 0^s.00019$	$-65^\circ\,26'\,55''.6866 \pm 0''.0005$	(1)
1995.1425	VLBI	$5^h\,28^m\,44^s.80247 \pm 0^s.00027$	$-65^\circ\,26'\,55''.6248 \pm 0''.0011$	(1)
1996.1507	VLBI	$5^h\,28^m\,44^s.81137 \pm 0^s.00013$	$-65^\circ\,26'\,55''.4852 \pm 0''.0003$	(1)
1996.3607	VLBI	$5^h\,28^m\,44^s.81776 \pm 0^s.00018$	$-65^\circ\,26'\,55''.3785 \pm 0''.0010$	(1)
		AB Dor Ba (=Rst 137 B)		
Epoch	Instrument	α(J2000)	δ(J2000)	Reference
1992.2329	VLBI	$5^h\,28^m\,44^s.39520 \pm 0^s.0007$	$-65^\circ\,26'\,47''.0676 \pm 0''.0024$	(2)
1992.6849	VLBI	$5^h\,28^m\,44^s.41973 \pm 0^s.0006$	$-65^\circ\,26'\,47''.0047 \pm 0''.0021$	(2)
1993.1233	VLBI	$5^h\,28^m\,44^s.40441 \pm 0^s.0008$	$-65^\circ\,26'\,46''.9869 \pm 0''.0028$	(2)
1994.8137	VLBI	$5^h\,28^m\,44^s.43687 \pm 0^s.0007$	$-65^\circ\,26'\,46''.5528 \pm 0''.0018$	(2)
1996.1507	VLBI	$5^h\,28^m\,44^s.42842 \pm 0^s.0005$	$-65^\circ\,26'\,46''.5773 \pm 0''.0010$	(2)
		Relative Position AB Dor A - AB Dor Ba		
Epoch	Instrument	Separation	P.A. (°)	Reference
1929	–	$10''.0$	339	(3)
1985.7	AAT	$9''.3 \pm 0''.3$	344 ± 5	(4)
1993.84	ATCA	$8''.90 \pm 0''.02$	345.2 ± 0.1	(5)
1994.2	Dutch/ESO	$8''.9 \pm 0''.1$	344.7 ± 0.3	(6)
2004.093	VLT/NACO	$9''.01 \pm 0''.01$	345.9 ± 0.3	(7)
		Relative Position AB Dor A - AB Dor C		
Epoch	Instrument	Separation	P.A. (°)	Reference
2004.093	VLT/NACO	$0''.156 \pm 0''.010$	$127 \pm 1^\circ$	(7)
		Relative Position AB Dor Ba - AB Dor Bb		
Epoch	Instrument	Separation	P.A. (°)	Reference
2004.098	VLT/NACO	$0''.062 \pm 0''.003$	$236.4 \pm 3.33^\circ$	(8)

(1) Guirado et al. (1997); (2) this paper; (3) Jeffers et al. (1963); (4) Innis et al. (1986); (5) J. Lim, personal communication (6) Martín & Brandner (1995); (7) Close et al. (2005); (8) Brandner et al. in preparation

2. To find a minimum of χ^2, as defined in Eq. (3), we used an iterative method, based on the Brent algorithm (Press et al. 1992). The minimum is defined such that the difference between the reduced-χ^2 of two successive iterations is significantly less than unity.
3. From the resulting orbital parameters, we then use Kepler's third law $[m_c^3/(m_a+m_c)^2 = a_1^3/P^2$, with a_1 the semimajor axis of the reflex orbit$]$ to estimate the mass m_c of AB Dor C.
4. We iterate the least squares fit (step 2) using as *a priori* values the new set of adjusted orbital parameters, and estimated m_c.
5. A final set of orbital parameters is obtained once the estimated m_c is *self-consistent*, that is, the difference between the value of m_c calculated in step 3 from consecutive sets of adjusted orbital parameters is negligible (i.e. $\ll 0.001\,M_\odot$).

The resulting orbital parameters, and the estimate of the mass of AB Dor C, are shown in Table 2 and represented in Fig. 1. These values are fully compatible with those given by CLG. However, our method shows the robustness of the determined orbit. Despite the wide range of parameter space investigated, the solution found for the reflex orbit of AB Dor A is unique (see Fig. 2). This is a remarkable result: for astrometrically determined orbits, Black & Scargle (1982) predicted a coupling between the proper motion and the orbital wobble, resulting in an underestimation of the period and semimajor axis. This coupling is present in the VLBI/Hipparcos data that only covers 51% of the reflex orbit. Our least-squares approach copes partially with this effect, since the astrometric and orbital parameters are estimated *simultaneously*. However, the VLT/NACO data not only extends significantly the observing time baseline, but represents *purely* orbital information, independent of proper motion and parallax effects. In practice, the combination of astrometric data of the primary star with astrometric data of the relative orbit improves the fit dramatically, constraining the orbital periods allowed by the astrometric data of the primary only.

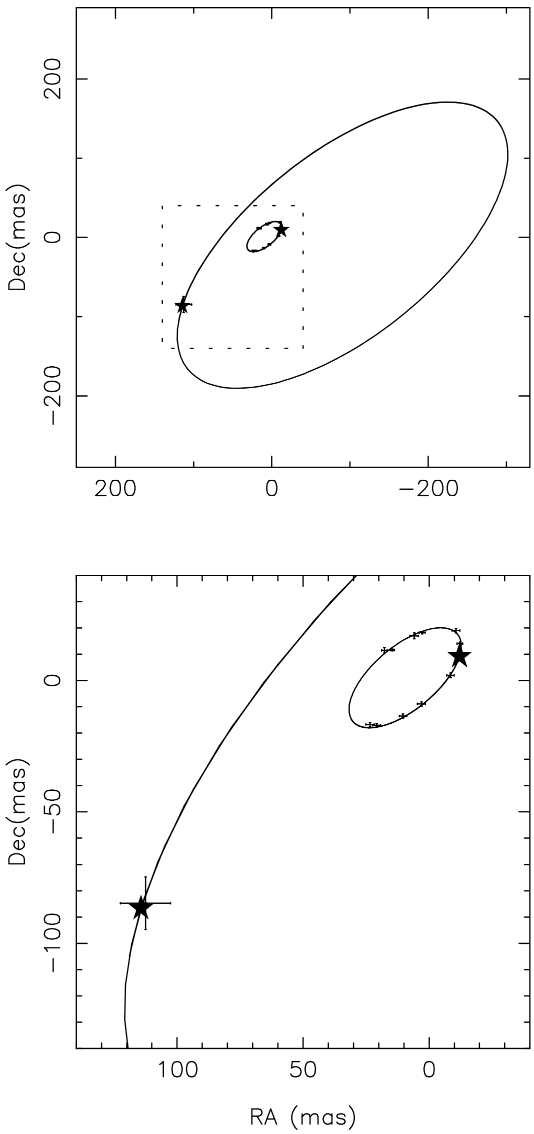

Fig. 1. Above: orbits of the pair AB Dor A (inner ellipse) and AB Dor C (outer ellipse). Below: blow up of the dotted square in the figure above. VLBI and Hipparcos data points are marked in AB Dor A's orbit, while the VLT/NACO AB Dor C position relative to AB Dor A is indicated in AB Dor C's ellipse. The star symbols over the orbits correspond the astrometric predictions at epoch 2004.093, based on the orbital elements given in Table 2.

In our case, the constraint is such that the only allowed period is 11.76±0.15 yr. In general, our results show the combination of different techniques is more effective than any one technique alone.

3.1.1. Error Analysis

Our least-squares procedure provides formal errors for the adjusted orbital parameters. However, other systematic contributions need to be taken into account. In particular, this includes the uncertainty associated to the mass of AB Dor A, which is a fixed parameter in our analysis

Table 2. J2000.0 astrometric and orbital parameters of AB Dor A

Parameter	
α [a]:	5 28 44.7948
δ^a:	−65 26 55.933
μ_α (s yr^{-1}):	0.0077 ± 0.0002
μ_δ (arcsec yr^{-1}):	0.1405 ± 0.0008
π (arcsec):	0.0664 ± 0.0005
P (yr):	11.76 ± 0.15
a_1 (arcsec):	0.0322 ± 0.0002
e:	0.60 ± 0.04
i (deg):	67 ± 4
ω (deg):	109 ± 9
Ω (deg):	133 ± 2
T_o:	1991.90 ± 0.04
m$_c$ (M$_\odot$)^b:	0.090 ± 0.003

[a] The reference epoch is 1993.0. Units of right ascension are hours, minutes, and seconds, and units of declination are degrees, arcminutes, and arcseconds.

[b] Mass range obtained from the period and semimajor axis via Kepler's third law. The mass adopted for the central star AB Dor A was 0.865±0.034 M$_\odot$.

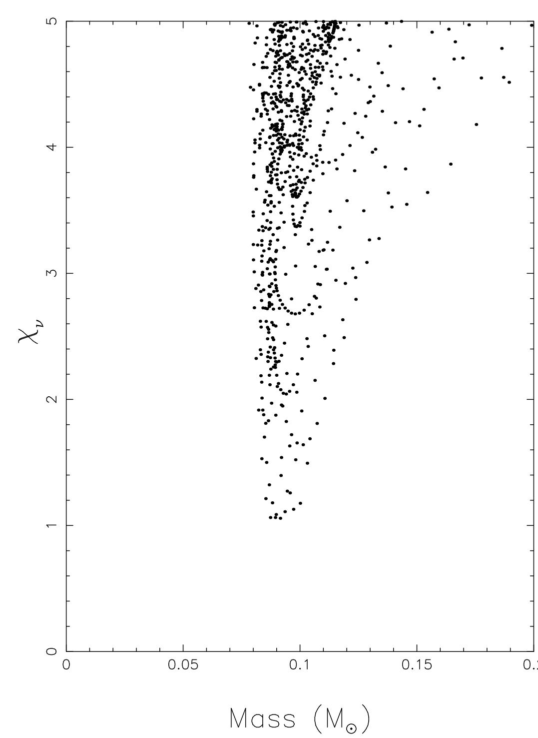

Fig. 2. Result of the exploration of the AB Dor A reflex orbit. A well-defined minimum is found for a mass companion of 0.090 M$_\odot$. See Sect. 3.1.

(0.865±0.034 M$_\odot$). To estimate this error contribution, we altered the mass of AB Dor A by one standard deviation and repeated the fitting procedure to obtain the change in the orbital parameters and the mass of AB Dor C. We note that this a conservative approach, since this technique fails

Table 3. J2000.0 VLBI astrometric parameters of AB Dor Ba

Parameter	
α [a]:	$5\,28\,44.4123 \pm 0.0002$
δ [b]:	$-65\,26\,46.9974 \pm 0.0015$
μ_α (s yr^{-1}):	0.0085 ± 0.0002
μ_δ (arcsec yr^{-1}):	0.134 ± 0.0012
π (arcsec):	0.0666 ± 0.0015

[a] The reference epoch is 1993.0. Units of right ascension are hours, minutes, and seconds, and units of declination are degrees, arcminutes, and arcseconds.

to account for the correlation of m_a with the rest of the parameters. The resulting parameter changes were added in quadrature with the formal errors of our fit (see Table 2). As expected, the 0.003 $M_\odot$ standard deviation of the mass of AB Dor C is dominated by the uncertainty in the mass of AB Dor A, while the standard deviations of the rest of the parameters are dominated by the statistical errors.

We also checked the dependence of our results on the choice of the *a priori* value of m_c in step 1 of our fitting procedure (Sect. 3.1). We found that the results are insensitive to this choice. The postfit residuals of the positions of AB Dor A exhibits an rms of ∼1 mas at each coordinate, consistent with the standard errors, and with no evidence, within uncertainties, of any further orbiting companion to AB Dor A.

3.2. VLBI Astrometric Parameters of AB Dor Ba

Innis et al. (1985) presented radial velocity measurements of AB Dor Ba, the 9” companion to AB Dor A. Their measurements do not differ from those of AB Dor A within the uncertainties. Additionally, Innis et al (1986) and Martín & Brandner (1995) reported close agreement between the proper motions of both stars. These results are strong arguments in favor of a physical association of both stars. We used the VLBI (absolute) positions of AB Dor Ba given in Table 1 to derive the parallax and proper motion via a least-squares fit. The results of this fit are presented in Table 3, which shows that the parallax of AB Dor Ba is coincident with that of AB Dor A to within the uncertainties, which provides independent and conclusive evidence for the association of both stars. Comparison of Table 1 and Table 3 shows that the proper motion of AB Dor Ba derived from the radio data appears significantly different to that of AB Dor A. Given the relatively small uncertainty of our determination, this does not contradict previous (and coarser) measurements of common proper motion. Rather, we interpret this extra proper motion of AB Dor Ba towards the south-east as a result of the orbital motion around AB Dor A (see Sect. 3.3).

The postfit residuals of AB Dor Ba show a systematic signature, both in right ascension and declination, which corresponds to a relatively high rms of ∼4 mas. The short time span between our separate VLBI observations makes it unlikely that this signature is an effect of the long-term gravitational interaction of AB Dor Ba with AB Dor A. Rather, this signature could be assigned to the 0.070” companion (ABDorBb) of AB Dor Ba seen in the VLT/NACO observations reported by CLG. As for the revision of the reflex orbit of AB Dor A, we attempted to get estimates of the orbital elements of the reflex motion of AB Dor Ba by combining the radio data with the VLT relative position between AB Dor Ba / AB Dor Bb (Table 1). However, our analysis did not yield useful bounds to the mass of this pair, showing that the number of data points is still insufficient and, more likely, they do not properly sample the expected short period of this tight pair.

3.3. AB Dor A / AB Dor Ba : evidence of orbital motion of AB Dor Ba

As stated in the previous section, evidence of the motion of AB Dor Ba around AB Dor A can be obtained from the radio data alone. In order to get more precise evidence of this orbital motion, we augmented our data set with relative positions AB Dor A/AB Dor Ba found in the literature (see Table 1). We then corrected all relative positions AB Dor A/AB Dor Ba for the reflex orbital motion of AB Dor A (Table 2), effectively referring the positions of AB Dor Ba to the center of mass of the AB Dor A/AB Dor C system.

We attempted to constrain the relative orbit of AB Dor A / AB Dor Ba following a similar analysis to that described in Sect. 3.1, fitting only the 7 parameters of the relative orbit. We sampled all possible periods up to 5000 years and eccentricities from 0 to 1. We selected as plausible orbits those whose reduced-χ^2 differs by 25% of the minimum. For each plausible orbit, the mass of the complete system was estimated from Kepler's third law, now expressed in terms of the parameters of the relative orbit:

$$\frac{(a/\pi)^3}{P^2} = M_{(A+C)} + M_{(Ba+Bb)} \qquad (4)$$

where $M_{(A+C)}$ and $M_{(Ba+Bb)}$ are the combined masses of AB Dor A/AB Dor C and AB Dor Ba / AB Dor Bb, respectively, a is the relative semimajor axis (arcsec), π is the parallax (arcsec; Table 2), and P is the period (yr). The poor coverage of the orbit favors a correlation between the orientation angles and the eccentricity, allowing a wide range of orbital parameters that fit our data equally well. However, a similar correlation between P and a imposes a constraint on the determination of the mass of the system via Eq. (4), which is represented in the histogram of Fig. 3. From the plausible orbits selected, more than 50% correspond to a total mass of the AB Doradus system in the interval 0.95−1.35 $M_\odot$ (see Fig. 4 for examples of plausible orbits). Larger masses are not excluded, but the required orbital configurations for masses outside this range occur with significantly reduced probability.

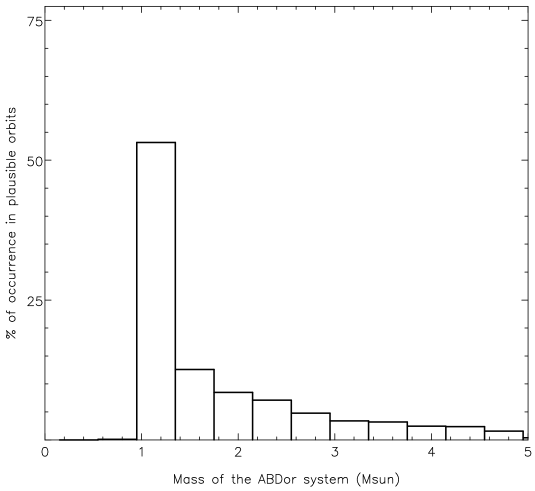

Fig. 3. Histogram of plausible orbits for the relative orbit of AB Dor Ba around AB Dor A. More than 50% of the plausible orbits correspond to a total mass of the system in the range $0.95-1.35\,M_\odot$.

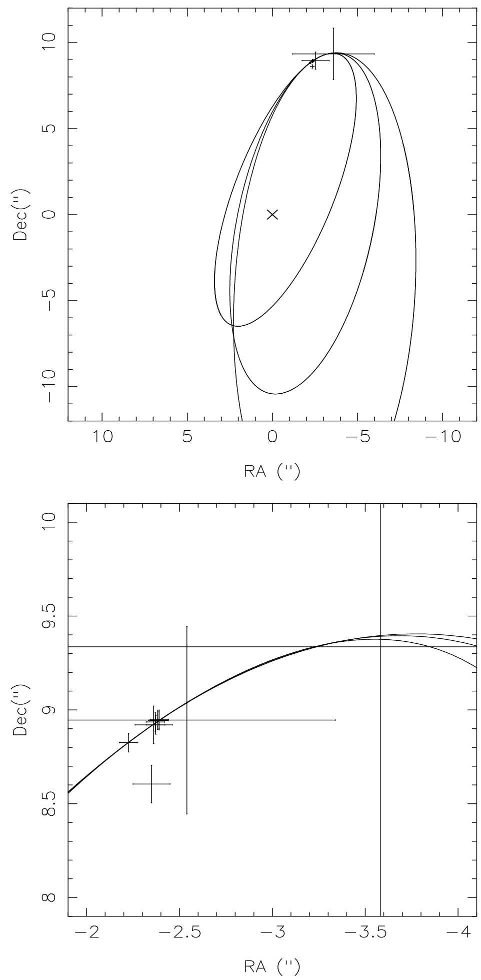

Fig. 4. Above: positions of AB Dor Ba with respect to the center of mass of AB Dor A/AB Dor C (see Table 1) and several allowed orbital solutions. The displayed orbits correspond to a total mass of the system in the range 0.95-1.35 $M_\odot$ with periods of 1400, 2300, and 4300 years. The cross at the origin indicates the position of AB Dor A/AB Dor C. Below: blow up of the region containing the measurements.

If we assume the total mass of the AB Doradus system lies in the interval $0.95-1.35\,M_\odot$, the combination with our estimate of $M_{(A+C)}$ ($0.956\pm0.035\,M_\odot$; see Sect. 1) suggests an upper bound to the mass of the pair AB Dor Ba / AB Dor Bb of $0.4\,M_\odot$. This upper limit to $M_{(Ba+Bb)}$ looks too coarse to calibrate evolutionary models. Nevertheless, it can be transformed into a bound to the age of this pair. To do this, we used the K-band 2MASS photometry of AB Dor Ba, and the K-band difference between AB Dor Ba and AB Dor Bb reported by CLG. The comparison with Baraffe et al. (1998) isochrones suggests an age for this pair in the range of 50−120 Myr. This range is compatible with previous values of the age of AB Dor Ba (30−100 Myr; Collier Cameron & Foing 1997). However, our age estimate for AB Dor Ba / AB Dor Bb is not conclusive: first, the masses of the individual components are yet to be determined, and second, there are indications that the evolutionary models might need revision, since they tend to underpredict masses for very young objects below $0.3\,M_\odot$ (CLG; Reiners et al. 2005).

4. Summary

We have revisited the different orbits in the quadruple system in AB Doradus. Paradoxically, this system, where the measurement of precise radial velocities is difficult due to the fast rotation of the main components, has become an extraordinary target for astrometric techniques in different bands of the electromagnetic spectrum. From our analysis of the available data, we have re-estimated the mass of the VLM star AB Dor C by using a least-square approach that combines the data from radio, optical, and infrared bands. Although the data do not cover a full orbit, the mass and orbital elements of AB Dor C are strongly constrained and fully compatible with those reported by CLG. Further monitoring of the reflex orbit of AB Dor A via VLBI observations, and of the relative orbit AB Dor A / AB Dor C via VLT/NACO observations, will result in independent estimates of the masses of the components of this pair. From the absolute radio positions of AB Dor Ba, we have determined the absolute sky motion (i.e. not referred to the motion of AB Dor A) of this star and, in particular, its parallax, which is identical, within the uncertainties, to that of AB Dor A. This confirms the association of both stars. The mass of AB Dor C serves as a precise calibration point for mass-luminosity relations of young VLM stars. Likewise, other components of AB Doradus may provide new calibration points for slightly higher masses. We have found evidence for the long-term orbital motion of AB Dor Ba / AB Dor Bb

around AB Dor A/AB Dor C. From an exploration of the multiple orbits that fit the available data we find that the most probable mass upper limit of the pair is 0.4 $M_{\odot}$. This limit maps into an age range of 50−120 Myr using the isochrones provided by Baraffe et al. (1998). Further monitoring with the appropriate sampling, both in radio and infrared, should provide the orbital elements of both the relative and reflex orbits of the pairs AB Dor A /AB Dor C and AB Dor Ba /AB Dor Bb, from which would follow precise, model-independent, estimates of the masses of the four components of this system.

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